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Symptomatology, Transmission, Infection and Control of Bean Mosaic in Idaho

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SUMMARY

1. Idaho grows approximately 75,000 acres of field and garden beans annually. A comparatively small portion of this acreage is devoted to the Robust variety; the remainder is given over to varieties which are susceptible to the mosaic disease; Great Northern and a number of snap bean varieties being the principal ones grown.

2. The leaves of mosaic-diseased plants usually show a curled or distorted condition in which patches of lighter green are found interspersed amid the normal green coloration. This gives the typical mottled or *mosaic* effect. Varieties differ widely in their response to the mosaic disease. Symptoms may be classified as primary and secondary; the primary symptoms being those of plants which have originated from diseased seed, the secondary symptoms those of plants which have become infected during their vegetative development.

3. Experiments have shown that temperatures conducive to optimum plant growth are also conducive to pronounced mosaic symptoms. Low temperatures which inhibit plant growth tend to inhibit the production of symptoms.

4. Mosaic-infected plants exposed to continuous light furnished by 1000-watt electric lamps grew much more rapidly and produced much severer symptoms than plants grown only under the normal daylight within the greenhouse.

5. It has been observed many times in the field that soils deficient in plant food, soils in poor physical condition, or soils lacking a sufficient amount of moisture, have a tendency to accentuate the symptoms of the mosaic disease of beans.

6. Great Northern bean plants with secondary mosaic infection produced seed which averaged 33 per cent mosaic when indexed in the greenhouse.

7. Great Northern plants with primary mosaic infection produced seed which averaged 48 per cent mosaic. In these same plants the mosaic-infected seed was not found

to be correlated with any particular position in the pod; the various seed positions within the pods apparently affording about equal chances for mosaic infection.

8. The size of pod, whether containing few or many seeds, was not correlated with the percentage of mosaic seed carried in either primary or secondary infected plants.

9. Insect sweepings of diseased and healthy bean fields have shown that insect populations associated with diseased fields are higher than with healthy fields.

10. In making artificial inoculations the highest percentage of infection was obtained with a combination leaf rubbing and leaf maceration method on young plants.

11. Low temperatures at which plants made slow growth tended to prolong the incubation period and were not conducive to a high percentage of infection in artificially inoculated plants.

12. Artificially inoculated plants which were exposed to the continuous light of a 1000-watt bulb in addition to normal daylight produced mosaic symptoms in a shorter time than similarly inoculated plants grown without supplementary light.

13. The most effective means of control is the use of resistant varieties or strains. The Robust variety is practically immune to mosaic. A number of selections of Great Northern have been made which show a considerable degree of resistance. Where it is desirable to grow susceptible varieties partial control can be obtained by the consistent roguing of an isolated seed plot.

SYMPTOMATOLOGY, TRANSMISSION, INFECTION AND CONTROL OF BEAN MOSAIC IN IDAHO

W. H. PIERCE and C. W. HUNGERFORD

INTRODUCTION

Bean Production in Idaho

Idaho is rapidly assuming an important position as a bean-producing state. Table I shows that the acreage in the state has been tripled since 1920, 25,000 acres being grown that year and 82,000 in 1928. In 1924, Idaho produced 1,268,000 bushels and in 1925, 1,584,000 bushels, ranking fourth among the states in total bean production for those years. The average acre yield of 23.7 bushels obtained in 1927 was the highest average of any state.

Table I

Beans: Acreage, Production and Yield in Idaho

Year	Acres (3)		Production Bushels (3)		Yield per Acre Bushels (3)	
1906	1,915	(1)	33,816	(1)		
1917	30,000	(2)	522,000	(2)	17.4	(2)
1918	43,000		860,000		20.0	
1919	36,000		396,000		11.0	
1920	25,000		288,000		11.5	
1921	18,000		216,000		12.0	
1922	26,000		364,000		14.0	
1923	45,000		990,000		22.0	
1924	65,000		1,268,000		19.5	
1925	72,000		1,584,000		22.0	
1926	54,000		999,000		18.5	
1927	72,000		1,706,000		23.7	
1928	82,000		1,476,000		18.0	

(1)—Federal Census.
(2)—Annual Reports, Idaho Bureau of Markets.
(3)—Idaho State Statistician's Reports.

The production of beans in Idaho is confined in general to two sections, one in the non-irrigated area of northern Idaho, and the other in the irrigated sections of southern Idaho.

The northern section is in the southeastern portion of the Palouse region in the counties of Latah, Lewis, Nez Perce, Clearwater and Idaho. A total of between 20,000 and 25,000 acres in this section is devoted to beans. Until recently the Navy pea and the Lady Washington varieties have been the principal varieties grown in this region. During the past five years many growers have adopted the Michigan Robust pea bean. Because of its resistance to the mosaic disease this variety has proved very popular and will no doubt eventually supplant all other varieties in the northern section.

The second bean producing area and the one principally responsible for Idaho's premier rank in point of yield per acre is in the irrigated sections of Twin Falls, Jerome, Cassia, Minidoka and Gooding Counties.

The acreage in this section has steadily increased since 1905 when only enough beans were raised for local consumption, until during the past few years, when the acreage has varied between 40,000 and 60,000 acres.

Prior to 1917 the principal varieties grown were the Navy pea and Lady Washington with some Red Mexican. With the introduction of the Great Northern in 1917 the above mentioned varieties fell into disfavor and are no longer grown in this section. The Great Northern is the chief commercial variety and comprises about 75 per cent of all beans grown. The remaining 25 per cent is made up of the Red Mexican and the canning varieties. The canning varieties are grown for seed companies on a contract basis.

THE DISEASE

Name

This virus trouble of beans has been referred to as "mosaic" by most authors and undoubtedly this is the term which should be applied to it. There are, however, a few other names popularly applied to this malady. Such names as curly leaf, curly top, and mottle top, are often heard because of their being more or less descriptive of the symptoms. Since bean mosaic has many symptoms in common with other mosaic diseases, and because of the confusion which arises when the term curly top is applied to it, this particular virus trouble will hereinafter be referred to as the *mosaic* disease of beans.

History

Bean mosaic is reported in the Plant Disease Bulletin (16) as occurring locally in New York in 1914 and as general and very severe in 1916 and 1917. Gloyer (8), however, states that it was observed in New York as early as

1908. In Michigan, Spragg and Down (23) observed mosaic in 1908, for they state that the Robust bean originated from a healthy individual plant that was selected in 1908 from among a lot of commercial pea beans containing mosaic. In 1917, Arkansas, California, Michigan, Minnesota, New York, Oregon, and Washington reported the disease to the Plant Disease Survey. Since 1917 new states have been reporting it nearly every year. At the end of the year 1927 mosaic of beans had been reported from a total of 42 states.

Recent evidence secured by the authors indicates that mosaic was present in at least one variety of beans as early as 1899. A collection of 150 bean varieties made in 1897-1899 by the Horticulture Department of the University of Idaho was recently turned over to the Department of Plant Pathology. An attempt was made to germinate a large number of these varieties and the following were found to be viable: New German Wax Flag; Guatemala Red (native variety); a strain of Frijol bayo from Matamoras, Mexico, and an unnamed variety No. 24. In plantings made in the greenhouse only two plants of Variety No. 24 were obtained; one of these exhibited mosaic mottling in the two seed leaves as soon as the plant emerged. As new leaves appeared unmistakable mosaic mottling could also be seen in them. Mosaic therefore must have been present in this variety at least as early as 1899.

Occurrence and Importance in Idaho

Survey records show that mosaic was first reported in Idaho as occurring locally in 1918, and that it was appearing in commercial fields and gardens in 1919. The loss due to mosaic in 1920 was estimated at 5 per cent and in 1921 at 10 per cent. In 1921 mosaic caused a reduction in the state of 24,000 bushels of beans. During the summer of 1925 a brief survey was made of the southern Idaho bean section, and mosaic was found in 100 per cent of the fields visited. Harter (9) made a survey of southern Idaho in 1927 and found mosaic infections varying from none to 85 per cent depending upon the variety.

The mosaic disease of beans became such a decided menace to the bean industry in Idaho that in 1926 a bean certification program was undertaken under the direction of the State Seed Commissioner. To be eligible for certification beans must be entirely free of anthracnose and bacterial blight, and must have less than 5 per cent mosaic during the early growing season and less than 2 per cent mosaic on a late season field inspection. The inspection of fields for certification ever since its institution has been

done by the Department of Plant Pathology. Certification was started with the Great Northern variety in southern Idaho and has not as yet been extended to other varieties, the Great Northern being the principal commercial variety in that section. In making the inspections for certification it was noted that certain more isolated areas were better adapted to the production of certified seed beans, than the areas where bean acreage was greater.

SYMPTOMATOLOGY OF THE DISEASE

General Field Symptoms

The symptoms of the mosaic disease of beans are very similar in many respects to the symptoms common to the mosaic diseases in general. The characteristic effect of mosaic is the ununiformity of leaf color. Irregular patches of a lighter green are found interspersed amid the normal green color. This gives the typical mottled or "mosaic" effect. These irregular patches of lighter green are often found as irregular elongated blotches running between the veins of the leaf toward the margin where they merge giving a light green margin to the leaf. With this type of mottling the outer margins of the leaf are nearly always found to be curled downward giving the leaf a convex upper surface. (Plate I.) In many cases the greater portions of the leaves will be light green, with dark green spots appearing as blisters or warts on the upper surface. In still other cases, although less frequently, the light green areas are dispersed intermittently, as irregular small spots, giving the whole leaf a granular appearance. With this type of mottling the leaves often show a ruffling about the margins, with no tendency to curl downward. A considerable number of plants have been observed on which the leaves affected with this granular mottling were only slightly distorted and appeared very much as a normal leaf with the exception of the mottling. (Plate I Fig. 1.)

Associated with mosaic is nearly always found a general dwarfed and spindling growth with a tendency to excessive branching, thus producing a more bushy type of plant than normal. (Plate II Fig. I.) Premature yellowing and dropping of the lower leaves may occur, but the uppermost leaves are nearly always late in maturing. Many fields have been observed that were delayed in maturity from ten to fifteen days. Diseased plants fail to set pods in extreme cases and always the yield is less than that of healthy plants.

The reduction in yield is brought about by a number of different factors. Many blossoms of mosaic plants drop off

without setting pods. Those pods that do set are often late in maturing and are harvested green, thus causing some loss through shrivelling of the seed. The pods produced on mosaic plants are usually smaller and contain a fewer number of seeds than pods produced on healthy plants.

Varietal Variations in Symptoms

Varieties of beans, *Phaseolus vulgaris*, differ widely in their response to the mosaic disease. Some varieties set few if any pods when once infection has taken place, while others may produce a good yield even though showing the symptoms on the leaves. The curling of the leaves often associated with the disease is much more pronounced on some varieties than others. It is nearly always associated with the Great Northern and Navy varieties under Idaho conditions. (Plate I.) With the wax and green podded varieties, there seems to be a general tendency toward less downward curling. However, infected leaves which do not curl, are often found to be much longer and narrower than normal leaves. This symptom is quite characteristic of all some varieties than others. It is nearly always associated varieties affected with mosaic. It is especially striking in young leaves which are just beginning to show infection. It is an important diagnostic symptom and one which is often overlooked or not interpreted as mosaic. (Plate I Figs. 1 and 3.)

Primary and Secondary Symptoms

In a study of bean mosaic symptoms it becomes necessary to differentiate between symptoms on plants which have originated from mosaic-infected seed, and symptoms on plants which have become infected during their vegetative development. The symptoms of the former type of infected plants will be termed primary symptoms, as it is from these plants that infection spreads to healthy plants. Symptoms on plants whch have become infected during the growing season will be termed secondary symptoms.

During the summer of 1928, a total of 200 bean plants of the Great Northern variety which had originated from mosaic-infected seed were observed throughout the growing season in experimental plots at Twin Falls. As soon as the plants were about four or five inches high the plot was carefully gone over and all plants which did not exhibit unmistakable symptoms of mosaic were pulled out, leaving only plants which had come from mosaic-infected seed.

Approximately 40 per cent of these plants became very severely dwarfed and curled and failed to set pods. The symptoms of mosaic were much more aggravated and severe

than is usually common with plants which become infected during the growing season. The remaining 60 per cent of the plants exhibited mosaic symptoms throughout the growing season, but they were not pronounced. The upper leaves of these plants were seldom curled and except for a mild mottling presented much the same appearance as healthy plants. Unmistakable mosaic mottling and some curling could always be found on the lower leaves. These plants produced a set of 15 pods or better despite the fact that they were mosaic diseased from the outset. At the end of the season this plot of mosaic-infected plants presented a better appearance than plants which had become diseased during the growing season, because of the fact that the upper leaves of the latter were very badly curled.

Racicot (17) makes the following statement in regard to transmission through the seed: "It is interesting to note that plants from diseased seed, and which had been diseased for at least three generations, showed no symptoms of mosaic this year, except about six plants from a total of 300."

Effect of Temperature on Symptoms

Dickson (3) makes the following statement with respect to temperature and symptoms: "In tests with bean mosaic in the greenhouse considerable difficulty was experienced in obtaining good symptoms, although seed from the same lot gave 85 per cent mosaic plants in the field, until the temperature at which the beans were grown was raised. The plants were still infectious in the 60°-70° F. greenhouse but the symptoms were completely masked except in a few old leaves."

Elmer (5) gives an account of a Mexican variety known as Berrendo that under western Oregon conditions did not exhibit mottling symptoms, but when grown under open field conditions at Ames, Iowa, did develop mosaic mottling, although to a less striking degree than certain other varieties of beans.

Johnson (10) found that soybean mosaic was inhibited at temperatures of from 26°-28° C. but he further states that pea bean mosaic can apparently persist at considerable higher temperatures.

Reddick (18) states that the symptoms of mosaic do not come out sharply in the greenhouse during the short cloudy days of winter, such as usually prevail at Ithaca, or in the field in summer if the weather is very warm and dry.

Racicot (17) accounts for the failure to show symptoms of bean plants from seed which had been diseased for at least three generations to an unusual amount of dull cloudy weather during the growing season.

Ever since the adoption of the bean certification program in the state of Idaho the Department of Plant Pathology has supplemented field inspections with thorough greenhouse tests of seed bean lots. Representative samples of seed lots to be tested are planted in the greenhouse during the winter and the amount of mosaic occurring in each lot is noted. This not only serves to check on the effectiveness of the last roguing but is useful in determining the amount of mosaic present in any unknown seed lot. In making the mosaic counts on these indexed beans it has been noted that the mosaic symptoms were for the most part *not* the typical definitely mottled and leaf-curled type found in the field, but were what might be termed a form of mild mosaic; the leaves showing mottling but with little tendency to curl downward. As the temperatures maintained in the greenhouse were considerably lower than the summer field temperatures it was thought that possibly low temperatures were the limiting factor in the production of symptoms. Hence, a preliminary experiment to determine the effect of temperature on mosaic development was carried out.

A sample of Great Northern seed containing 25 per cent mosaic disease in the field was used for the experiment. Three lots of 50 seeds each were planted and grown at three different temperatures, 79° F., 71° F. and 65° F. All three series were planted February 28, 1927, and were kept free from insect vectors at all times. On April 2, notes were taken on the amount of mosaic occurring and also on the types of symptoms associated with the different temperatures. (Table II.)

Table II

Effect of Temperature on Mosaic Development

Ave. Air Temp.	No. Seed Planted	No. Germinated	Per cent Germinated	No. Diseased	Per cent Diseased	Type of Symptoms
79° F.	50	31	62	7	23	Severe dwarfing, curling and mottling
71° F.	50	25	50	3	12	One mottled only. Two curled and mottled
65° F.	50	20	40	1	5	One mottled only

It is important to note that of the diseased plants occurring at the different temperatures those grown at 79° F. showed severe dwarfing, curling, and mottling, and those at 71° F. showed two plants curled and mottled and one plant with mottling only. At 65° F. the one diseased plant showed no tendency to curl whatever. From this preliminary experiment it seems that low temperatures tend to reduce the severity of the symptoms of the mosaic disease on beans.

On November 7, 1928, a similar experiment was started. A series of 40 potted plants, which had previously (October 8) been inoculated and infected artificially by hand with mosaic, were placed under temperature conditions varying from 50° to 60° F. A similar series of 40 plants were placed under higher temperature conditions where the temperature varied between 70° and 80°.

On December 1, 24 days after the experiment was started, the low temperature series exhibited mottling on nearly all the plants but there was very little downward curling of the margins. There was a very noticeable tendency toward excessive branching, with the production of small leaves with short petioles. In the high temperature series the leaves of the plants were curled downward at the margins, but rather irregularly so, differing somewhat from the more even and regular curling found in the field. In other respects the plants tended toward a more normal growth than those held at between 50°-60° F., there being no excessive branching.

Effect of Light Upon Symptoms

The observations of Racicot (17) and of Reddick (18) relative to the failure of diseased plants to show symptoms during cloudy weather, seemed to suggest that possibly the lack of light was also a limiting factor in the production of symptoms.

For the purpose of determining the effect of light upon mosaic symptoms, 72 plants were inoculated with macerated mosaic bean tissue, and placed in double-walled glass cages under three different amounts of light, but under uniform temperature ranges. A series of 24 plants was placed in cage 1, over which was suspended a 1000-watt electric light equipped with a large reflector. In addition to normal daylight the plants in this cage were grown under continuous light furnished by this electric light. The temperature in this cage averaged 27° C. during the course of the experiment. A second series of 24 plants was in cage 2, under normal daylight supplemented by light furnished by a 1000-watt electric light during the day only. The temperature

in this cage averaged 26° C. A third series of 24 plants was placed in cage 3, and grown with no supplementary light. The cage was also protected from the light cast by the two 1000-watt light bulbs over the other two cages. This cage was equipped with a heating unit to maintain a temperature near temperatures in cages 1 and 2, which were under lights. The temperature in cage 3 averaged 28° C.

The symptoms produced by the plants grown in cage 1 under continuous light were very pronounced. (Plate III Figs. 1 and 2.) The leaves were severely curled and distorted. The dark green areas of the leaf mottling appeared as raised blisters. The mosaic symptoms on the plants grown in cage 2 under supplementary light during the day were somewhat less pronounced than those obtained under continuous light. A mild mottling appeared but the dark green areas were not apreciably raised. Considerable curling was present as is shown in Plate III Figs. 3 and 4. In the check series in cage 3, the symptoms were very mild. There was practically no mottling and only a very slight amount of curling. (Plate III Figs. 5 and 6.)

Effect of Soil on Symptoms

It has been frequently noted by the writers that soils in poor physical condition and soils low in plant food materials tend to intensify mosaic symptoms. In the summer of 1928 the Department of Plant Pathology maintained an experimental plot of 1¼ acres in the Twin Falls section. The north border of this plot had supported a row of trees for several years, but in 1926 they had been cut down and removed, leaving the soil in poor physical condition as well as depleted its food supply. For a distance of about 20 feet from this border, beans did not do well and those that became infected with the mosaic disease were very severely dwarfed and curled. Plants on good soil in the same plot that became infected with mosaic during the growing season made nearly as large a growth as healthy plants.

Owens (15), in reporting the mosaic disease in Oregon, stated that 40 acres in Lane County were severely diseased, 10 acres of the 40 being approximately 100 per cent mosaic, and the remainder ranging from a trace to over 50 per cent mosaic. The 10 acres which were 100 per cent infected were found to be on light sandy soil, which shaded off into a heavier and less sandy soil. The percentages of mosaic were noted to vary directly with the variation in the soil.

It seems quite probable that the apparent differences in mosaic infection on the two types of soils were differences in severity of symptoms rather than in percentages of infection. Although no mention is made of the moisture condi-

tions in the light sandy soil and the heavier soil, it is entirely possible that the apparent high mosaic infection on the sandy soil may have been due somewhat to lack of moisture. In this connection Barss (1) states that in dry weather and on soils lacking sufficient moisture the symptoms are more pronounced.

Seed Transmission of Bean Mosaic

Kendrick and Gardner (12) found that seed from mosaic-infected soybean plants produced from 10 to 25 per cent mosaic seedlings, with some variation between the varieties used. McClintock (13) observed that seed from mosaic diseased lima beans gave rise to mosaic seedlings, but he makes no statement as to the percentage. Reddick and Stewart (19) (20) (21) proved conclusively that the pea bean mosaic virus was transmitted in the seed. With one variety they found that about 50 per cent of the seed from diseased plants produced mosaic infected seedlings. They also found a variation in varieties, some varieties producing somewhat more than 50 per cent mosaic-infected seed.

Somewhat contrary to this Burkholder and Muller (2) state that seeds from a bean plant affected with true mosaic seldom give rise to 50 per cent diseased plants. None of the above investigators state whether or not the seed used in their determinations was from plants which had originated from mosaic-infected seed or whether the plants had become infected during their growing season. In this connection Fajardo (6) states that a higher percentage of infected seed was obtained from plants grown from infected seed than from plants inoculated during their vegetative developments.

Due to the inherent tendency of different varieties to produce varying percentages of diseased seed and because of the tendency of *seed* infected and *vegetative* infected plants to produce different percentages of infected seed, the following experiments were carried out with the Great Northern variety in order that more accurate data on seed transmission in this variety might be secured.

Seed Transmission in Plants with Secondary Infection

In the fall of 1927 seed from 30 mosaic-infected plants from Parma, Idaho, was planted in the greenhouse. No record was kept in the field of the plants which had originated from infected seed, but previous indexing of the parent seed stock had shown it to be about 10 per cent mosaic infected.

The number of mosaic seedlings which developed from each of the 30 plants grown in the greenhouse was noted. Out of a total of 526 plants, 174 exhibited mosaic symptoms,

a percentage of 33.07. The complete data on these plants is recorded in Table III.

Table III

Showing Number and Percent of Diseased Seedlings from Indexed Plants Grown at Parma—1927

Plant	Number Germinated Seeds	Number Mosaic Plants	Per cent Mosaic Plants
A	48	8	16.6
B	25	13	52.0
C	40	24	60.0
D	12	9	75.0
E	17	2	11.7
F	11	0	0.0
G	11	7	63.6
H	24	8	33.3
I	15	9	60.0
J	11	7	63.6
K	10	0	0.0
L	24	18	75.0
M	14	5	35.7
N	22	5	22.7
O	23	9	39.1
P	18	10	55.5
Q	10	0	0.0
R	21	0	0.0
S	15	2	13.3
T	12	4	33.3
U	25	5	20.0
V	20	2	10.0
W	15	2	10.0
X	21	11	52.3
Y	18	3	16.6
Z	11	2	18.1
AA	7	2	25.8
BB	1	1	100.0
CC	10	1	8.3
DD	15	5	33.3
Total	526	174	33.07

In making the planting of the first 17 of the above plants (plants A to Q inclusive) each pod of each plant was numbered and planted separately. Notes were kept on the number of seeds in each pod and on the number of diseased and healthy plants coming from each.

From the data obtained from the above plantings the percentage of the 1-seeded pods carrying no mosaic infection and the percentage in which the one seed was mosaic infected was calculated. Likewise the 2, 3, 4 and 5-seeded pods were segregated according to the number of mosaic seeds which each contained, and the percentage of pods in each class calculuated. (Table IV.)

Table IV

Percentage of Pods Containing 0, 1, 2, 3, 4, and 5 Mosaic Infected Seeds

	0-mosaic Seeds	1-mosaic Seed	2-mosaic Seeds	3-mosaic Seeds	4-mosaic Seeds	5-mosaic Seeds
1 seeded Pods	77.8	22.2				
2 seeded Pods	66.6	23.8	9.5			
3 seeded Pods	34.7	43.4	8.7	13.1		
4 seeded Pods	43.9	29.2	19.5	4.8	2.4	
5 seeded Pods	46.6	26.6	20.0	0.0	0.0	6.6

A study of this table shows no apparent correlation of the number of seeds per pod to the percentage of infection carried.

Regardless of the number of seeds per pod the percentage of pods carrying no mosaic seeds is considerably greater than the percentage of pods carrying 100 per cent infection. There is in general a rather regular decline in percentage of pods between no infection and 100 per cent infection.

Seed Transmission in Plants with Primary Infection

A similar series of plant and pod indexing was carried out in the fall of 1928, with plants which had originated from diseased seed, thus differing from the 1927 series which was made up of plants 90 per cent of which had become mosaic infected during their vegetative development.

The plants used in the 1928 series were Great Northern plants grown at Twin Falls, in a plot from which all healthy plants had been removed when the plants were seedlings, thereby assuring that all the plants remaining had developed from mosaic infected seed.

Twenty-five of these plants were pod indexed in the greenhouse. The seed from each pod was also indexed; that is, beginning at the stem end of the pods the seeds were planted in consecutive order, so that data could be secured on the mosaic infection occurring at various positions within the pods.

There were 792 plants which germinated in this series; of these 385 or 18.6 per cent were unmistakably affected with the mosaic disease.

Table V

Showing Number and Per cent of Diseased Seedlings from Indexed Plants Grown at Twin Falls, Idaho—1928

Plant	No. Seeds	No. Ger.	No. Dis.	Per cent Dis.	Per cent Germinated
1	69	55	29	52.7	80.0
2	67	47	29	61.7	70.1
3	36	29	16	55.1	80.5
4	28	27	0	0.0	96.4
5	33	28	8	28.5	84.8
6	32	14	8	57.1	43.7
7	11	7	5	71.4	63.6
8	21	18	14	77.7	85.7
9	31	23	15	65.2	74.1
10	36	20	15	75.0	55.5
11	32	11	7	63.6	34.3
12	64	50	27	54.0	78.1
13	25	17	12	70.5	68.0
14	31	17	8	47.1	54.8
15	57	38	9	23.6	66.6
16	60	34	23	67.6	56.6
17	79	56	34	60.7	70.8
18	50	36	17	47.2	72.0
19	118	66	28	42.4	55.9
20	91	59	0	0.0	64.8
21	20	12	11	91.6	60.0
22	63	44	19	43.1	70.0
23	34	25	15	60.0	73.5
24	38	23	14	60.8	60.5
25	79	36	22	61.1	45.5
Total	1205	792	385	48.6	65.7

The percentages of pods bearing either none, 1, 2, 3, 4, 5 or 6 mosaic seeds were calculated, and are recorded in Table VI.

From an inspection of this table it is seen, that the percentages of the 1, 2, 3, 4, 5, and 6 seeded pods which contained no mosaic seeds were approximately the same, the percentages varying between 33.3 and 40.6 per cent. The percentages of the various sized pods which contained 1 mosaic seed were not quite so well grouped, although the greater number approximated about 22 per cent. With the pods containing 2 mosaic seeds, we find that the percentages are again rather closely grouped, being 25.0 per cent of the 2 seeded pods, 29.6 per cent of the 3 seeded pods, 16.8 per cent of the 4 seeded, 27.2 per cent of the 5 seeded, and 22.5 per cent of the 6 seeded pods. Beyond this point the percentages of pods bearing 3, 4, 5 and 6 mosaic seeds rapidly falls off as the number of mosaic seeds per pod increases, as

Table VI

Percentages of Pods Bearing 0, 1, 2, 3, 4, 5, and 6 Mosaic Seeds, Data from 25 Plants—From Mosaic Infected Seed—1928

	0 Mosaic	1 Mosaic Seed	2 Mosaic Seeds	3 Mosaic Seeds	4 Mosaic Seeds	5 Mosaic Seeds	6 Mosaic Seeds
1 Seeded Pods	33.3	66.6					
2 Seeded Pods	36.1	38.8	25.0				
3 Seeded Pods	40.6	21.8	29.6	7.8			
4 Seeded Pods	36.3	22.0	16.8	18.2	6.5		
5 Seeded Pods	37.6	10.4	27.2	7.8	15.5	1.3	
6 Seeded Pods	35.5	22.5	22.5	6.4	9.7	0.0	3.2

was pointed out in the case of the plants indexed in 1927 which were largely mosaic infected during their vegetative growth.

In order to determine the percentage of infected seed occurring at different positions in the pod, data on the plants which had arisen from the seeds occupying the first position next to the stem end of the pod were segregated, and the number of healthy plants and the number showing mosaic infection were counted and the percentages of each calculated. The percentages of healthy and diseased plants coming from seeds occupying the 2nd, 3rd, 4th and 5th, and also the end positions in the pods, were also calculated. (Table VII.)

The percentages of diseased plants from the seed from the various positions in the pod ranged between 42.5 per cent and 53.3 per cent. This is about the range that might be expected, as the average percentage of mosaic disease occurring in the entire population was 48.6 as shown in Table V.

The seeds occupying the first position in the pod developed the lowest percentage of mosaic, 42.5 per cent, or six per cent below the population average of 48.6. The highest percentage of disease, 53.3 per cent, was associated with seed No. 2. However, neither of these extreme variations are divergent enough to preclude the generalization that seeds are apparently about equally subject to mosaic infection any place within the pod.

Table VII

Percentages of Mosaic Infected Seeds Occupying Different Positions in the Pod. Data from 25 Plants from Mosaic Infected Seed—1928

Seed Position from Stem End	Total Pods	No. Seeds Not Inf.	No. Seeds Diseased	Percent Not Inf.	Percent Infected
Seed No. 1	202	116	86	57.4	42.5
Seed No. 2	197	92	105	46.7	53.3
Seed No. 3	172	89	83	51.8	48.2
Seed No. 4	120	57	63	47.5	52.5
Seed No. 5	77	39	38	50.7	49.3
End Seed	232	116	116	50.0	50.0

Insect Transmission

Nelson (14) with cage experiments proved that the bean mosaic virus could be transferred by aphids, *Macrosiphum solanifolii,* Ashmead. Smith (22) working with cowpea mosaic established that bean leaf beetles, *Ceratoma trifurcata,* Forst., which had fed for one day on diseased plants and were then transferred to healthy plants transmitted the disease in almost every case. Elmer (5) states that aphids, (sp. not mentioned) and mealy bugs, *Pseudococcus maritimus* Ehr, facilitated mosaic infection from Solanaceae to species (beans and cowpeas) where hand inoculation failed. Fajardo (6) reports that infection was obtained with mealy bugs and three species of mosaic reared aphids, but that negative results were obtained with leaf-hoppers, twelve-spotted cucumber beetles, striped cucumber beetles, red spider, thrips, tarnished plant bug, and white fly.

As previously pointed out the area closely surrounding Twin Falls and Jerome is not adapted to the growing of certified seed. In this area clean seed cannot be kept clean even for one season, the spread in the field being too rapid to be overcome by roguing. In making the inspections for certification in 1927, a field two miles northeast of Twin Falls was found with 20 per cent mosaic toward

the end of the season, and a field ten miles south of Twin Falls, planted from the same seed lot, showed less than 3 per cent mosaic. These observations were followed up with insect sweepings of both fields. The species and numbers of the insects, considered as possible insect vectors, which were found in the fields, are recorded in Table VIII. Included in this table are also the records of insects found on redscale, *Atriplex rosea*, Russian thistle, *Salsola pestifer*, alfalfa and sweet clover, which were growing together along the irrigation ditches bordering the above bean fields. The number of insects collected in 200 sweeps on a field of alfalfa which bordered the bean field which contained only 3 per cent mosaic is also included.

Table VIII

Results of Insect Sweepings of Bean Fields, Twin Falls, Idaho—1927

Number of Sweeps	250	250	250	200
Insects	Field with 20 Per cent Mosaic	Field with 3 Per cent Mosaic	Irrigation Ditch Atriplex Rosea Russian Thistle Alfalfa Sweet Clover	Alfalfa
Tarnished plant bug (*Lygus pratensis*, Linn.)	65	28	257	573
Buffalo treehopper (*Ceresa bubalus*, Fab.)	17	0	22	1
Leafhoppers (Sp. Undet.)	21	8	8	22
Beet leafhoppers (*Eutettix tenellus*, Baker)	0	0	8	0
Leaf bugs (Sp. of Miridae)	13	4	17	3
Chalcid Flies (*Bruchophagus funebris*, Howard)	0	0	6	97
Green aphids (Sp. Undet.)	0	0	2	15

It has been consistently observed throughout the mosaic disease investigations that there is almost always a higher percentage of mosaic infection along the borders of bean fields than in the centers of them. These observations are closely correlated with the numbers of insects found. In the center of large bean fields there are very few insects present, but on the borders the numbers are much greater,

varying directly, however, with the prevalence of insects on the border crops, or weeds.

Aside from the fact that there was a greater number of insects associated with high mosaic infections, than with low mosaic infections, there was little light shed upon the insect vector problem by the insect sweepings. However, the insects which have been consistently associated with the mosaic disease were used in cage experiments during the past two summers.

In 1927 a specie of green leafhopper, green aphids collected from alfalfa, and the tarnished plant bug, were tested under cages for ability to transmit the mosaic disease. These insects were caged on mosaic diseased beans for 4 or 5 days before being transferred to the healthy plants. Negative results were obtained with all these insects.

In 1928, the tarnished plant bug, a specie of green aphid from alfalfa, the buffalo treehopper, and an undetermined specie of black aphid from beans were the insects used in the cage experiments. The black aphids were the only insects which transmitted the mosaic disease in this test. (Table IX.)

Table IX

Results of Cage Experiments on Insect Transmission of Bean Mosaic, Twin Falls—1928

Insects Used	Number of Plants Inoc.	Number of Plants Inf.	Percentage of Infection
Tarnished plant bug *(Lygus pratensis)*	9	0	0
Alfalfa aphid (Sp. Undet.)	9	0	0
Buffalo Treehopper *(Ceresa bubalus)*	5	0	0
Black Aphid (Sp. Undet.)	6	3	50

Both close observation and insect sweepings of many plants in a considerable number of fields have shown the aphid infestation to be very light. It has not been possible by field observations to correlate the spread of mosaic with aphids, even though cage experiments have proven them to be vectors. However, a few aphids may cause more spread than is thought, or on the other hand, there may be more aphids present at certain periods during the summer than has heretofore been observed. From all evidence it seems that the rapid spread of mosaic in the field is undoubtedly correlated with insect transmission. The problem of determining and identifying the particular vectors involved is

one which will be followed up with the aid of the entomologists of the Idaho Agricultural Experiment Station.

INFECTION STUDIES

Method and Time of Inoculation

In beginning a study of a mosaic disease one of the first prerequisites is a method of inoculation which can be relied upon to give maximum infection. The nature of mosaic diseases in general necessitates the determining of infection by an analysis of symptoms alone. The infectious qualities of any given inoculum cannot be determined culturally or microscopically but only through inoculation and the resultant production of infection or non-infection upon the host plant.

There is a paucity of instances recorded in the literature of successful artificial transmissions of bean mosaic. Reddick and Stewart (20), however, in testing the susceptibility of bean varieties to the mosaic disease, made a number of successful inoculations by rubbing the undersides of the young leaves of healthy plants with slightly crushed leaves of diseased plants. The leaves of the test plants were rubbed sufficiently to be injured, and in most cases the plants were placed in a moist chamber for 24 hours. In a number of cases, however, even with highly susceptible varieties they did not secure 100 per cent infection. They attributed their failure to a weakness in technique because of a lack of understanding of the nature of the infective principle.

Elmer (5) in cross inoculation studies reports that he never artificially infected beans or cowpeas with mosaic, even though the inoculum was from plants belonging to the same species. He was, however, successful in transmitting mosaic from beans to tomato and tobacco by artificial inoculations with mosaic bean tissue macerated in a solution of 30 per cent acetone. Fernow (7) obtained infection on beans in three out of twelve inoculations by the method recommended by Reddick and Stewart (20). Fajardo (6) has recently found that infection of from 80 to 100 per cent can be obtained from a modified leaf mutiliation method.

Methods of inoculation which give good infection with one mosaic upon a specific host cannot always be relied upon to give a high percentage of infection with a different combination of mosaic and host. As an example, Reddick and Stewart (21) found it impossible to transmit bean mosaic by hypodermic injections, differing in this respect from tobacco mosaic. The following experiment was undertaken for the purpose of determining the effectiveness of various methods of inoculation under the greenhouse conditions pre-

vailing at Moscow, Idaho, during the fall, winter, and early spring months.

Outline of Experiment

Four methods of inoculation were used at the beginning of these studies, namely, (1) puncture through the inoculum by applying macerated pulp of diseased leaves to healthy plants and then pricking through the inoculum into the healthy leaves with a sterile needle; (2) by rubbing the undersides of young leaves of healthy plants with slightly crushed mosaic leaf tissue; (3) inoculation at joint of branch by the insertion of macerated mosaic leaf tissue into the plant at that point; (4) inoculation by puncture through the inoculum method, by applying pulp of diseased beans macerated in a 30 per cent acetone medium to the leaves of healthy plants and then pricking through the inoculum into the healthy leaves with a sterile needle. All macerations were made in a sterile mortar, and the needle used in making inoculations was flamed after each inoculation. The operator's hands were thoroughly washed with soap and water after each plant was inoculated.

Immediately after inoculation each plant was well watered and covered with a moistened bell jar for 48 hours. A sufficient number of plants was potted to allow for inoculation by the four methods outlined at three different stages of growth: (1) as soon as the plants emerged the cotyledons and first leaves were inoculated; (2) when the second leaves were fully expanded, or about two weeks later than the first inoculation; (3) at the early blossom stage, about four weeks later than the second inoculation. Ten plants were inoculated at each of the above stages, making a total of 30 plants inoculated by each of the four methods.

The Little Navy variety of beans was used throughout the experiment. The strain used had been grown in the greenhouse previously and was found to develop about 5 per cent mosaic. Nevertheless, a series of check plants was run with all the types and stages of inoculations, in order to check more accurately on the number of plants arising from infected seed.

Results

The inoculation method of rubbing the young leaves of healthy plants with slightly crushed mosaic leaves gave a 50 per cent infection, the highest of all the methods employed. This, however, is not sufficiently high to be of much use in determining the infectiousness of given inoculums. An analysis of the results obtained on the various times of inoculation indicates that the stage of growth at which a plant

is most susceptible to mosaic is that stage at which the second leaves have become expanded.

This percentage, 46 per cent, was again so low that considerable error would undoubtedly result in making infection studies. An attempt was therefore made to increase the percentage of infection by more rigorous methods of inoculation. Twenty-two plants of the Great Northern variety were inoculated by rubbing the undersides of the leaves, which were large enough to permit it, with freshly gathered mosaic-infected leaves. The rubbing was continued until the healthy leaves were thoroughly bruised and presented a water-soaked appearance on the upper surface. The leaves which were too small to be rubbed handily, that is, the youngest leaves of the plant, were inoculated with material prepared by grinding in a mortar young leaves showing mosaic symptoms. A very small amount of white quartz sand was added to aid in grinding and thoroughly macerating the mosaic leaves. A generous portion of this inoculum was then applied to the young leaves of the test plants. Then with a dissecting needle the young leaves were thoroughly punctured and the inoculum worked into the leaves. A few of the small leaves to which inoculum had been applied were pinched and rolled between the thumb and forefinger. The inoculated plants were then immediately covered with moistened bell jars for 48 hours.

Ten plants were inoculated in a similar manner with macerated leaves of healthy plants. The operator's hands were washed with soap and water and the dissecting needle was sterilized in a flame after inoculating each plant to avoid possible transference of mosaic from plants in which the symptoms of mosaic may have been masked. These inoculations were made on April 20, 1928. On the fourth of May, fourteen days later, 17 of the 22 plants inoculated showed mosaic symptoms. This was a percentage infection of 77.2.

In October 1928 two similar series of inoculations were made. In the first series a total of 48 Great Northern plants were inoculated on October 22. On November 3, there were 36 plants or 75 per cent of the total number inoculated showing mosaic symptoms. On October 24 a second series consisting of 36 plants were inoculated, and 29 of these exhibited mosaic symptoms on November 5. A percentage infection of 80.8 was obtained on this series. Complete data on these two series of inoculations are recorded in Table X.

Table X

Results of Mosaic Inoculation Experiments with Great Northern Beans—Moscow, Idaho—October 1928

Series Number	Number Plants Inoculated	Number of Check Plants	Number of Plants Infected	Number of Checks Infected	Percentage of Inoculated Plants Infected	Incubation Period (Days)	Temperature Range of Experiment
I	48	48	36	0	75	12	20-28° C.
II	36	12	29	0	80.8	12	20-28° C.

Effect of Temperature upon Infection

In making the foregoing inoculation experiments in the greenhouse it was noted that a higher percentage of infection was obtained in late spring and early fall than during the winter and early spring months. As the greenhouse was not equipped to maintain as high temperatures during the winter as was possible during warmer weather, it was thought that the low percentage of infection obtained in the earlier work was directly attributable to unfavorable temperature relations.

During the summer of 1928 the university greenhouses were connected up with a more adequate heating system, and as a result the plants used in the experiments conducted in the fall of 1928 (Table X) were maintained at a much higher temperature than was previously possible. At this higher temperature the incubation periods averaged between twelve and fourteen days, which was considerably shorter than the time required for infection under lower temperature conditions. These observations are found to conform to the data obtained from the following temperature experiment:

Three series of inoculations were made, each series consisting of ten inoculated and ten uninoculated Navy pea bean plants. The inoculation of each series was carried out in the same manner. All inoculations were made by rubbing the undersides of young leaves of healthy plants with leaves from diseased plants. The very small leaves were inoculated by placing macerated diseased leaves on their surfaces and puncturing them through this material. The inoculated plants were then covered with moistened bell jars for 48 hours. Each series was maintained at a different temperature for a period of twenty days.

Series I was kept in an unheated room where the soil temperature averaged 47° F. Series II was grown in the greenhouse at an average soil temperature of 60° F., and Series III was grown in a glass enclosed high temperature chamber where the average soil temperature maintained was 70° F.

Table XI

Effect of Temperature on Mosaic Infection Under Greenhouse Conditions. Moscow, Idaho—1927

Temperature	Number of Plants Inoculated and Number of Checks	Number Plants Infected	Number Artificially Infected	Per cent Artificially Infected	Incubation Period (Days)	Date Inoculated	Date of Appearance of Symptoms
47° F. 8°-9° C.	10 Inoc. 10 Cks.	5 4	2	20	24	April 22	May 16
60° F 15°-16° C.	10 Inoc. 10 Cks.	9 4	6	60	20	April 22	May 12
70° F. 21° C.	10 Inoc. 10 Cks.	9 0	6	60	18	April 22	May 10

At the end of twenty days (Table XI), the plants held at the two higher temperatures were showing a considerable amount of mosaic, but the 47° F. series did not exhibit any mosaic symptoms at that time. This low temperature series was then placed in the 70° F. chamber for a period of two weeks to determine whether or not the plants inoculated at 47° F. were actually infected or whether they did not become infected at the low temperature. At the end of the two weeks' period 5 of the 10 inoculated plants were mosaiced. In each of the other two series of inoculations 9 of the 10 plants became infected. (Table XI.) The number of plants listed in the table as artificially infected was calculated by subtracting the average number of check plants showing mosaic symptoms from the number of inoculated plants showing infection in each case.

It is seen from the data shown in Table XI that a much higher percentage of infection was obtained at the higher temperatures. It was also noted that the length of the incubation period varied at the different temperatures, being eighteen days at 70° F., twenty days at 60° F., and twenty-four days when held at 47° F. for the first twenty days and then at 70° F. for the remainder of the period.

These findings are supported in the main by the work of other investigators. The work is this connection, however, is rather limited. Reddick and Stewart (20) in the report of their work on bean mosaic make only a short statement to the effect that high temperature and high humidity slightly favor mosaic infection. Doolittle (4) working with cucumber mosaic on cucumbers found that increasing the soil temperature from 27° C. to 30° C. reduced the incubation period from six to three days and produced a higher percentage of infection. With soil temperatures below 18° C. the disease did not develop. In a discussion of the plant virus problem, Johnson (11) points out that temperature is perhaps the only factor to which the virus diseases studied are particularly sensitive, differing from most parasitic diseases in that moisture does not play an important part in infection. He further points out that in the potato the optimal temperature for infection as measured by the length of the incubation period is near 25° C., but at this temperature the symptoms are much less marked than at 15° C.

Bean mosaic, however, seems to differ from potato mosaic, as shown by Johnson (11) in that the optimum temperature for infection in beans, as measured by the length of the incubation period, is also near the optimum temperature for the best production of symptoms.

Effect of Light upon Infection

An experiment to determine the effect of light upon mosaic symptoms has been previously described. In this experiment notes were taken on the number of plants infected and the length of the incubation periods in each of the three series of inoculated plants grown under varying exposures to light. (Table XII.)

Table XII

Data on Experiment to Determine Effect of Light upon Mosaic Infection—Greenhouse—Moscow, Idaho—1929

Cage Number	Exposure to Supplementary Light, Furnished by 1000-Watt Electric Lights	Average Temperature	Total Number Plants Inoculated	Total Number Plants Infected	Incubation Period Days	Severity of Symptoms
1	Continuous	27° C.	24	5	11	Severe
2	During Day	26° C.	24	8	14	Moderate
3	No Supplementary Light	28° C.	24	7	15	Slight

An inspection of Table XII reveals that the amount of light was indirectly proportional to the length of the incubation period. Under continuous light the first symptoms of mosaic appeared in eleven days; under supplementary light during the day, symptoms appeared in fourteen days; and in the check series the first symptoms appeared on the fifteenth day. It is significant to note that under continuous light the incubation period was shorter; the mosaic symptoms were more pronounced; and the plants grew much faster than plants without continuous light.

If these preliminary experiments relative to the effect of light and temperature on the incubation period and on the severity of symptoms of bean mosaic give any clue as to the nature of the casual agency, they seem to suggest at least that whatever the exact cause may be, its transmission and development in the plant is very intimately associated with plant growth.

Control

The systematic nature of bean mosaic precludes the using of sprays and dusts in the field as a means of control. Also the fact that the infective principle is carried within the seed, does not permit controlling the disease by seed treatment. Reddick and Stewart (21) have shown that the thermal death point of the mosaic causative agent is too near the temperature at which the seed germ is killed to permit the use of heat in inactivating the mosaic virus within the seed.

Isolation and Roguing

It has been demonstrated in the Twin Falls section that clean seed of Great Northern and of other susceptible varieties will by no means entirely control mosaic in *unisolated* areas. However, since the adoption of certification of Great Northern beans it has been possible to produce mosaic-free crops in isolated areas unfavorable for dissemination, providing reasonably clean seed is planted and the fields thoroughly rogued during the growing season. The rules for state bean seed certification specify that only fields located on the borders of the irrigation tracts or fields otherwise favorably located for the control of mosaic shall be eligible for certification. All fields entered for certification must be isolated at least 600 feet from other bean fields. Fields should be rogued continuously and all infected plants removed as soon as they appear.

Early versus Late Planting

It has been quite consistently observed in the Twin Falls section that the early planted beans usually suffer less from

mosaic than late planted beans. This is probably correlated with less insect activity in the early spring, thus allowing the beans to attain a good growth before being attacked. Unless the growing season is favorable for beans during the latter half of the month of May, early planting is apt to result in losses through poor germination, bald heads, or frost sufficient to offset the advantage of planting before the first week of June, which is the average planting date in the Twin Falls section.

Resistant Varieties and Selections

The only safe precaution against the rapid dissemination of mosaic in the field is the use of resistant varieties or strains.

The Michigan Robust Pea Bean, originally found by F. A. Spragg (23), has been proven to be practically immune to mosaic, and for this reason has supplanted other varieties of pea beans in Michigan and New York, and has practically solved the mosaic problem in northern Idaho.

In southern Idaho the Robust has failed to supplant the Great Northern, the latter being responsible for the very rapid development of the bean industry in the southern section by virtue of its prolific and early maturing qualities. Recent investigations have shown that the Great Northern variety possesses a higher degree of resistance to root rot troubles and to the curly top disease than does the Robust.

For the purpose of developing a mosaic-resistant bean which will be adapted to southern Idaho experiments are being conducted at Twin Falls by the Idaho Agricultural Experiment Station. A number of strains of Great Northern, and a few segregants of a Robust and Great Northern cross, are showing a considerable degree of resistance to mosaic, and the writers feel that it is along this line that the problem of control will be satisfactorily solved. Fig. 4, Plate II shows one promising selection in comparison with commercial stock of the Great Northern bean.

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PLATE I

Figure 1. Left: Healthy bean leaves of Great Northern variety. Right: Mosaic-infected leaves of Great Northern beans grown at low temperatures in the greenhouse.

Figure 2. Mosaic-infected Great Northern bean leaves showing typical curling symptom nearly always associated with the disease in the field.

Figures 3 and 4. Young leaves just beginning to show mosaic infection. Note the curling and the elongated tips of the leaflets.

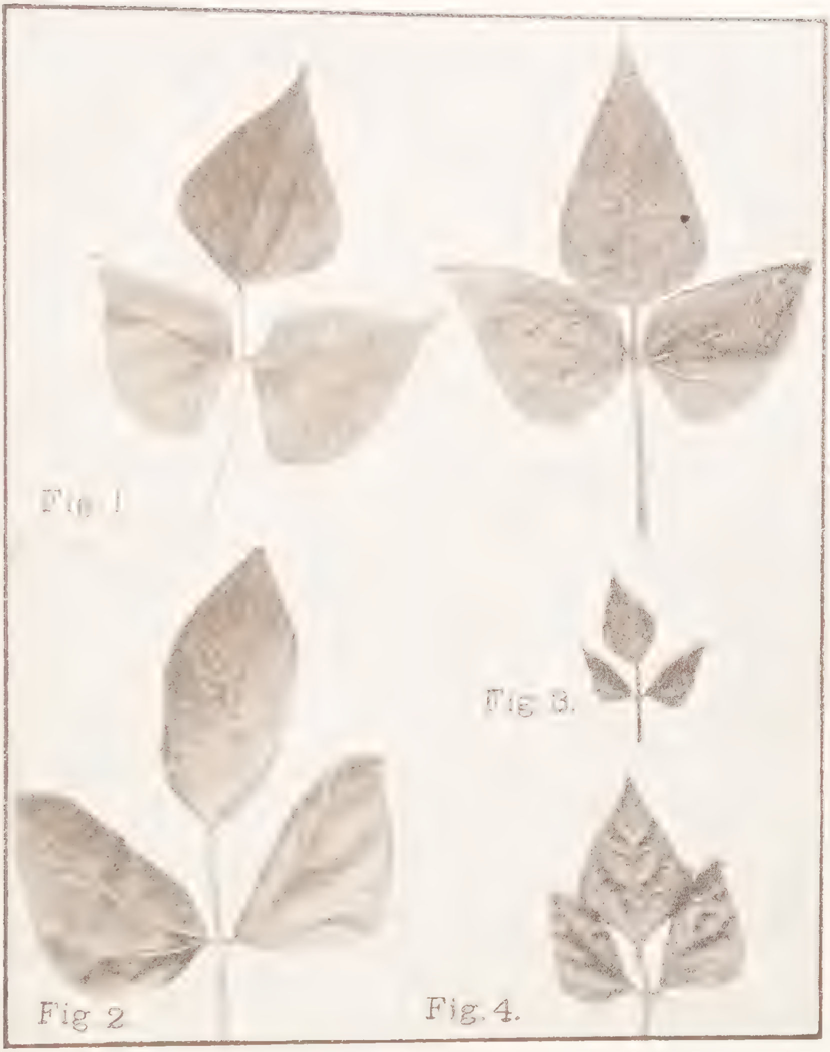

Plate I

PLATE II

Figure 1. Left: Healthy Kentucky Wonder bean plant. Right: Mosaic-diseased Kentucky Wonder bean plant showing typical curling and dwarfing of plant.

Figure 2. Great Northern bean plant in the field typically affected with mosaic.

Figure 3. Left: Stringless Refugee bean plant with severe infection of mosaic. Note the absence of pods. Right: Healthy Stringless Refugee plant.

Figure 4. The first two rows on the left are healthy Great Northern beans. The adjoining rows are Great Northern beans affected with the mosaic disease.

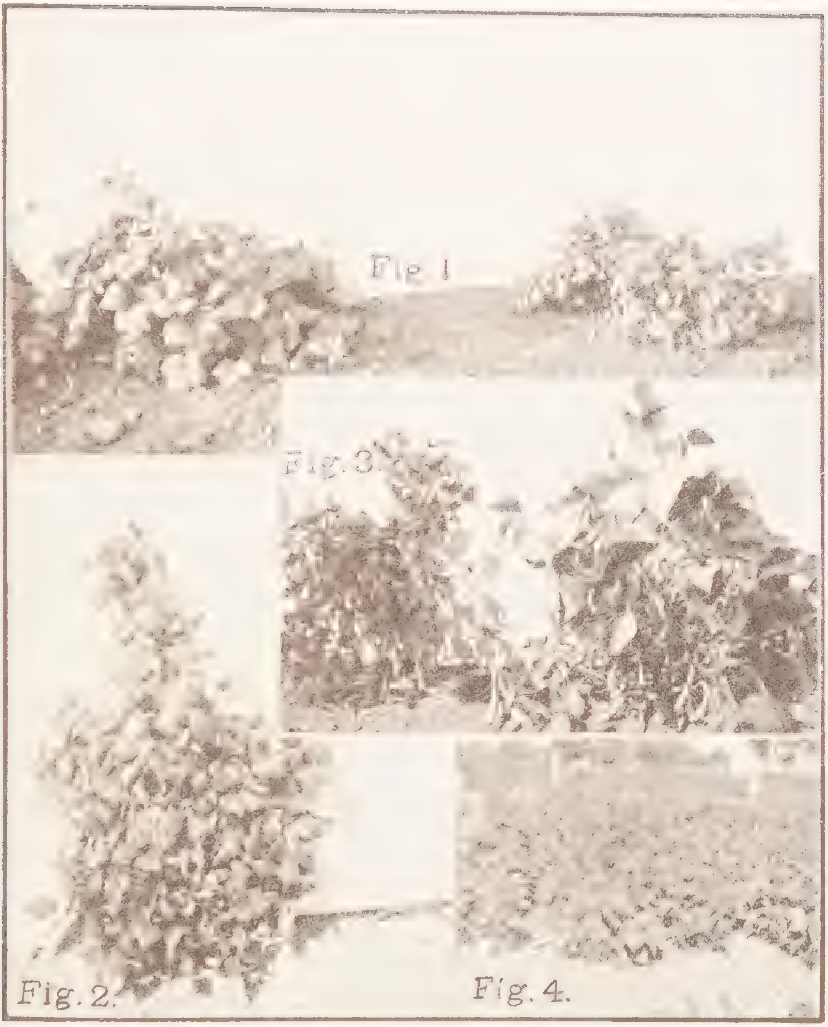

Plate II

PLATE III

Figure 1. Healthy Great Northern bean plants grown in the greenhouse under continuous light furnished by 1000 watt electric lights.

Figure 2. Mosaic-infected Great Northern plants grown under same conditions as plants in Figure 1. Note the severe curling and distortion of the leaves.

Figure 3. Healthy Great Northern bean plant grown in the greenhouse with supplementary light furnished by 1000 watt electric lights, during the day only.

Figure 4. Mosaic-infected Great Northern plant grown under same conditions as plant in Figure 3. There is some curling of the leaves but less so than plant in Figure 2.

Figure 5. Healthy Great Northern bean plants grown in the greenhouse with no supplementary light.

Figure 6. Mosaic-infected Great Northern plants grown under same conditions as plants in Figure 5. Note only a slight amount of leaf curling.

Plate III